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in PPAR γ Mediated Treatment of Breast Cancer

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13. ABSTRACT (Maximum 200 Words) Cyclopentenone prostaglandin derivatives of arachidonic acid are promising molecules in the fight against cancer, but their mechanism of action is not well understood. Several investigators have shown that the terminal derivative of prostaglandin J ₂ (PGJ ₂) metabolism 15deoxy $\Delta^{12,14}$ PGJ ₂ (15dPGJ ₂) is a potent activator of the nuclear hormone receptor peroxisome proliferator activated receptor gamma (PPAR γ), but 15dPGJ ₂ effects can be mediated by PPAR γ -dependent and PPAR γ -independent mechanisms. A candidate PPAR γ independent mechanism is 15dPGJ ₂ induced inhibition of NF κ B via covalent modification of IKK, I κ B α and the DNA binding domain of NF κ B. We have shown previously that 15dPGJ ₂ potentially induces apoptosis of breast cancer cells and that 15dPGJ ₂ regulates gene expression critical to apoptosis. Specifically, 15dPGJ ₂ induces potent and irreversible S-phase arrest that is correlated with >2-fold increased expression of at least 20 of 1,176 genes as determined by cDNA differential display. Inhibition of RNA synthesis, using actinomycin D, or protein synthesis, using cycloheximide, abrogates apoptosis induced by 15dPGJ ₂ in breast cancer cells. Additionally, caspase-3 activation follows the induction of gene transcription and the peptide inhibitor ZVAD-fmk blocks apoptosis. These data show that de novo gene transcription is necessary for 15dPGJ ₂ induced apoptosis in breast cancer cells, that inhibition of NF κ B plays a minor role in 15dPGJ ₂ induced apoptosis and identifies cyclopentenone prostaglandins and potential therapeutic molecules for PPAR γ mediated apoptosis in breast cancer.				
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Introduction

The peroxisome proliferator activated receptor gamma (PPAR γ), is a potential therapeutic target for the treatment of breast cancer but the endogenous ligand for PPAR γ is not yet known. Recent data suggest that the endogenous ligand of PPAR γ may be a bioactive metabolite of arachidonic acid that is synthesized in normal breast tissue. Activation of PPAR γ with different agonists (e.g. 15deoxy Δ 12,14PGJ₂, troglitazone) elicits different physiological responses in breast cancer cells (i.e. differentiation or apoptosis) raising questions of the role PPAR γ plays in normal breast cell physiology. Results from our initial experiments show that prostaglandin metabolites of arachidonic acid inhibit cell cycle progression of MDA-MB-231 breast cancer cells. This cell cycle block induces apoptosis of breast cancer cells and inhibits tumor formation in nude mice. We hypothesize that human breast cancer cell lines (and human breast cancer tumors) have aberrant PPAR γ mediated signal transduction pathways or contain disrupted pathways for the metabolism of fatty acid derivatives that act as PPAR γ agonists. Understanding the metabolism of fatty acids in breast cancer cells, and elucidating the molecular and signal transduction events that are mediated by PPAR γ agonists may lead to novel strategies for the prevention and treatment of breast cancer.

Body

There is extensive literature on the use of retinoic acid and its derivatives, acting through their receptors (RAR and RXR), to arrest or reverse cancer in both animals and humans. Another member of the nuclear receptor superfamily, peroxisome proliferator activated receptor-gamma (PPAR γ), has an important role in fat metabolism and adipocyte differentiation. Although its natural ligand is not yet known, synthetic thiazolidinediones, certain fatty acids and metabolites of arachidonic acid, activate PPAR γ . Recent data reveal that PPAR γ is expressed in colonic tumors and metastatic breast adenocarcinomas, which raises the critical question of its functional significance in human cancers. RXR α and PPAR γ agonists together have been shown to induce apoptosis of estrogen receptor positive breast cancer cell lines *in vitro* and attenuate tumor growth in mice. Our studies show that prostaglandin agonists of PPAR γ alone inhibit cell cycle progression of both estrogen receptor positive and negative breast cancer cell lines via apoptosis and inhibit tumor formation in nude mice.

There are three specific aims for the pre-doctoral research hypothesis that human breast cancer cell lines (and human breast cancer tumors) have aberrant PPAR γ mediated signal transduction pathways or contain disrupted pathways for the metabolism of fatty acid derivatives that act as PPAR γ agonists.

- 1) The first aim is to determine the physiologic activities of different PPAR γ agonists on the proliferation of human breast cancer cell lines and primary human breast cancer cells. We will extend our published findings to include other natural prostanoid and eicosanoid agonists (e.g. PGE₂, DHA), synthetic PPAR γ agonists (e.g. BRL49653, ciglitazone) and co-activators that can potentiate the effects of PPAR γ agonists (e.g. 9-*cis*-retinoic acid, all-*trans*-retinoic acid).
- 2) The second aim is to determine the molecular mechanisms and signal transduction events that underlie PPAR γ mediated differentiation or apoptosis in breast cancer cells.
- 3) The third aim is to determine the metabolism of J-series prostaglandins in normal breast tissue and breast cancer cells.

Aim 1: Our studies of other natural and synthetic PPAR γ agonists show that several arachidonic acid (AA) metabolites, including 5- and 15-HETEs and 5- and 15-oxo-EETs, are activators of PPAR γ . However, of all the naturally occurring metabolites tested, the terminal derivative of prostaglandin D₂ metabolism, 15deoxy $\Delta^{12,14}$ PGJ₂ (15dPGJ₂), remains the most potent (Figure 1). In addition, after attending the PPARs Keystone Symposium in February 2000, Mr. Clay was successful in obtaining a chemically synthesized selective PPAR γ agonist (GW347845X) from GlaxoSmithKlein (GSK). This compound was shown to be 10,000 fold more potent in inducing PPAR γ activation by luciferase reporter assays. Although Mr. Clay received this compound only recently, he has confirmed the reports by GSK and will add this compound to his arsenal of PPAR γ agonists in determining the physiologic activity of these compounds in breast cancer cell lines. A major accomplishment of Mr. Clay's was his observation that the published literature cites different physiologic outcomes in various cancer cell lines according to the concentration of PPAR γ agonist used. To this end, Mr. Clay authored a review article that documented the differing biological effects of PPAR γ activation in diverse cell types (1). Furthermore, Mr. Clay undertook the responsibility of determining if these diverse and opposing biologic outcomes occur in a single cell type (2). Mr. Clay will investigate if agonists of RXR α , the heterodimeric partner of PPAR γ , could potentiate the observed responses.

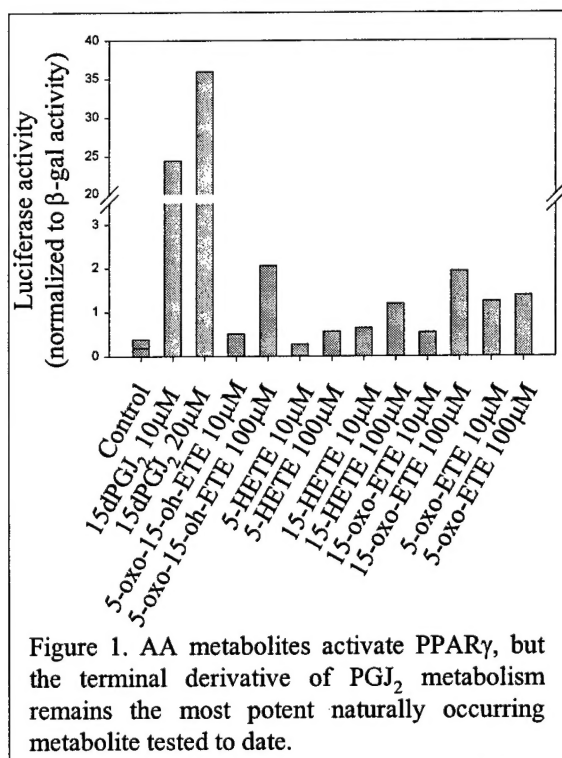


Figure 1. AA metabolites activate PPAR γ , but the terminal derivative of PGJ₂ metabolism remains the most potent naturally occurring metabolite tested to date.

Aim 2: The molecular mechanisms and signal transduction events that underlie PPAR γ mediated differentiation or apoptosis in breast cancer cells are complex and not well understood. Mr. Clay has achieved great milestones in elucidating parts of these pathways. In a screen of 1,176 gene products by cDNA array analysis, Mr. Clay identified particular gene products that are increased in breast cancer cell lines after treatment with 15dPGJ₂. Of these, the expression of the cyclin dependent kinase inhibitors p21^{Waf1/Cip1} (p21) and p27^{Kip1} (p27) and the cyclins D and E is increased >2 fold. Additionally, the expression of several genes involved in DNA maintenance and repair is decreased >2 fold. Mr. Clay has performed *post hoc* analysis of p21 and p27 expression by Western blot analysis to confirm the results from the cDNA array (Figure 2) and will establish cell lines that express a dominant negative form of p21. Additionally, Mr. Clay has followed up on published reports of the effects of 15dPGJ₂ in other cell systems to devise a potential mechanism by which 15dPGJ₂, or other cyclopentenone prostaglandins, may exert such potent anti-neoplastic activity in a variety of cancer cell types (Appendix 1). These studies have resulted in the preparation of a manuscript that Mr. Clay intends to submit to *The Journal of Biological Chemistry* (3). Mr. Clay will continue this line of investigation to include other gene products and further elucidate the mechanisms described. Furthermore, Mr. Clay has established breast cancer cell lines that express a dominant negative form of PPAR γ . He has shown that transcriptional activation of PPAR γ by 15dPGJ₂ is blocked in these cells (Figure 3) and will continue to investigate how the dominant negative cell lines affect apoptosis induced by 15dPGJ₂. Recent publications suggest that 15dPGJ₂ negatively regulates the NF κ B pathway of gene transcription. Mr. Clay has begun to investigate this critical pathway using NF κ B inhibitors, Bay and Cape, and by establishing cell lines that express a dominant negative form of the NF κ B regulator I κ B α .

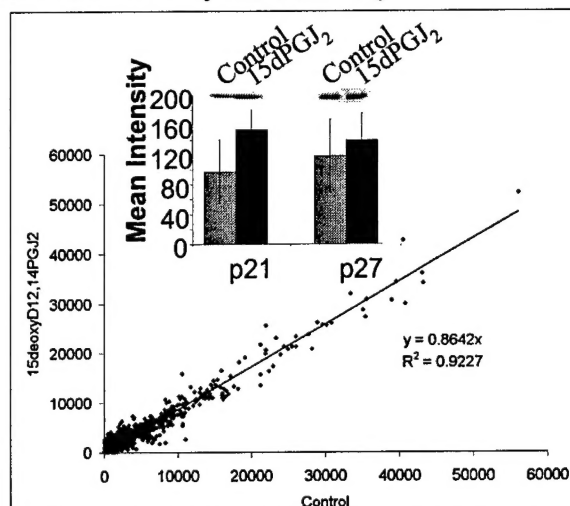


Figure 2. cDNA array analysis of 1,176 genes shows that the majority of expressed gene do not change in response to treatment with 15dPGJ₂. The mRNA expression of cyclin dependent kinases p21 and p27 was increased >2 fold. Expression of p21 and p27 protein was confirmed by Western blot analysis.

Aim 3: The studies of the metabolism of J-series prostaglandins in normal breast tissue and breast cancer cells are in the beginning stages. Mr. Clay was successful in obtaining a small amount of [³H]15dPGJ₂ through a collaborative effort with Dr. Kirk Maxey of Cayman Chemical. Using [³H]15dPGJ₂ to follow the metabolism of 15dPGJ₂ in the breast cancer cell line MDA-MB-231, Mr. Clay has noted that after 12 hours, the majority of label is still present as 15dPGJ₂. In this preliminary study, 66% of [³H]15dPGJ₂ was recovered after 12 hours. The remaining 44% was in the form of more polar metabolites as determined by thin layer chromatography (TLC). These derivative may represent a class of reactive oxygen species (ROS) that further activate PPAR γ (Appendix 1). Mr. Clay was unable to determine the structure of these polar metabolites, or their biological activity, due to the limited quantity of material, but Mr. Clay has enlisted the analytical expertise of the laboratory of Dr. Robert Murphy (National Jewish Research Center, Denver, Colorado) to assist with the determination of these structures by negative ion chemical ionization gas chromatography/tandem mass spectrometry (NICI GC/MS/MS). Moreover, Mr. Clay has obtained critical reagents for the study of prostaglandin metabolism. Specifically, Mr. Clay has been promised the use of immuno-reactive antibodies to specific AA metabolizing enzymes. These include antibodies to fatty acid CoA ligase (FACL4), the enzyme that ligates free AA to Co-enzyme A, cyclooxygenase 2 (COX-2), the enzyme which catalyzes the oxidation and cyclization of AA to produce prostaglandin G₂ (PGG₂) and prostaglandin H₂ (PGH₂) and prostaglandin D₂ synthase (PGDS), the enzyme that catalyzes the formation of PGD₂ from PGG₂/PGH₂. These reagents will be helpful for the investigation of enzymatic levels of these critical metabolizing enzymes. In addition, enzymatic activity assay kits are readily available.

Key Research Accomplishments

- 15deoxy $\Delta^{12,14}$ PGJ₂ remains the most potent naturally occurring PPAR γ agonist identified.
- The degree of PPAR γ activation dictates distinct and opposing biological responses in breast cancer cells, ranging from increased proliferation to differentiation and apoptosis.
- 15deoxy $\Delta^{12,14}$ PGJ₂ induced apoptosis requires *de novo* expression of critical gene products.
- Dominant negative expression of PPAR γ completely abrogates transcriptional activation induced by 15deoxy $\Delta^{12,14}$ PGJ₂.
- The mechanism of action of 15deoxy $\Delta^{12,14}$ PGJ₂ is not limited to PPAR γ activation. 15deoxy $\Delta^{12,14}$ PGJ₂ can inhibit NF κ B, activate PPAR γ and can stimulate reactive oxygen species generation. Together, these events lead to induced expression of key gene products that are involved in PPAR γ mediated apoptosis in breast cancer cells.
- 15deoxy $\Delta^{12,14}$ PGJ₂ is metabolized to polar derivatives by breast cancer cells.

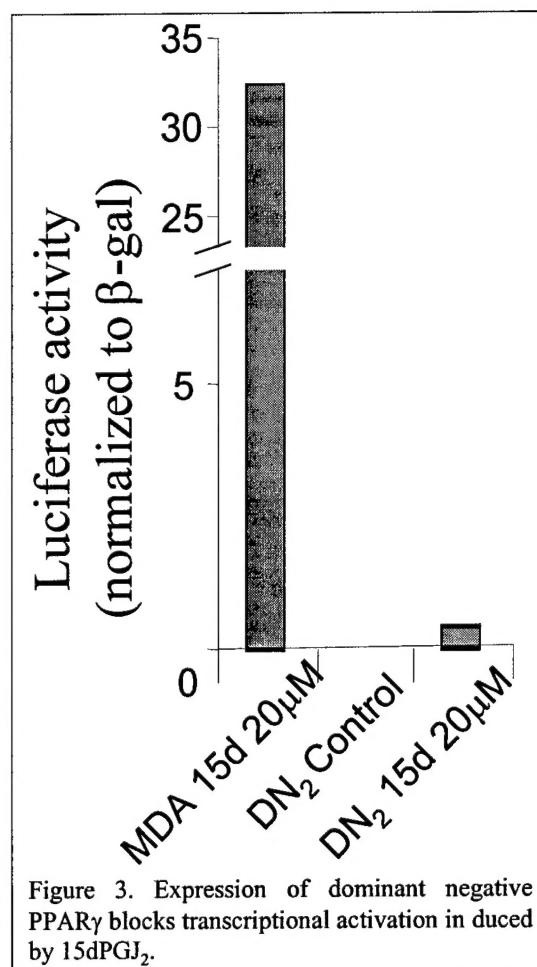
Reportable Outcomes

• Manuscripts

1. **Clay CE**, Namen AM, Fonteh AN, Atsumi G, High KP, Chilton FH, 2000, 15deoxy $\Delta^{12,14}$ PGJ₂ induces diverse biological responses via PPAR γ activation in cancer cells. *Prostaglandins and Other Lipid Mediators* 62:23-32
2. **Clay CE**, Namen AM, Atsumi G, Trimboli AJ, Fonteh AN, High KP, Chilton FH, 2001, The magnitude of PPAR γ activation is associated with important and seemingly opposite biological responses in breast cancer cells. *Journal of Investigational Medicine* (in press)
3. **Clay CE**, Atsumi G, High KP, Chilton FH. 2001, 15deoxy $\Delta^{12,14}$ PGJ₂ induced apoptosis is not mediated by NF κ B in breast cancer cells: requirement for *de novo* gene expression. (in preparation)
4. **Clay CE**, Atsumi G, High KP, Chilton FH. 2001, PPAR γ dependent and independent mechanisms of apoptosis in breast cancer cells (in preparation)

• Abstracts

1. *PPAR γ induced apoptosis requires de novo gene expression that is suppressed by a dominant negative mutant in breast cancer cells.* FASEB: Receptors and Signal Transduction, Copper Mountain, CO July 2-9, 2000
2. *15deoxy $\Delta^{12,14}$ PGJ₂ inhibits breast cancer cell proliferation via PPAR γ activation.* International Society for Preventive Oncology, 5th International Meeting, Geneva, Switzerland, October 28-31, 2000, Satellite Symposium October 29, 2000
3. *PPAR γ induced apoptosis requires de novo gene expression that is suppressed by a dominant negative mutant in breast cancer cells.* Wake Forest University, Breast Cancer Center of Excellence, Winston Salem, NC, November 16, 2000
4. *PPAR γ induced apoptosis requires de novo gene expression that is suppressed by a dominant negative mutant in breast cancer cells.* Keystone Symposium: PPARs a transcription odyssey, Keystone, CO, February 2-9, 2001



- Presentations

1. *PPAR γ induced biologic responses require de novo gene expression that is suppressed by a dominant negative mutant in breast cancer cells.* Wake Forest University Cancer Center Faculty Retreat, Winston-Salem, NC, August 11-12, 2000
2. *15deoxy $\Delta^{12,14}$ PGJ₂ induced apoptosis is suppressed by a PPAR γ dominant negative.* South Eastern Regional Lipid Conference, Cashiers, NC, November 1-3, 2000
3. *Mechanisms of Apoptosis in breast cancer cells: 15deoxy $\Delta^{12,14}$ PGJ₂ and PPAR γ .* University of Colorado Health Sciences Center, Denver, CO, February 9, 2001.

- Development of cell lines

1. PPAR γ Dominant Negative
2. I κ B α Dominant Negative
3. p21 Dominant Negative

- Awards

1. Comprehensive Cancer Center Award: Best graduate student presentation (monetary award) *PPAR γ induced biologic changes require de novo gene expression that is suppressed by a dominant negative mutant in breast cancer cells.* Wake Forest University Cancer Center Faculty Retreat, August 11-12, 2000
2. Avanti Founder's Award: Best graduate student presentation (monetary award and conference expenses) *15deoxy $\Delta^{12,14}$ PGJ₂ induced apoptosis is suppressed by a PPAR γ dominant negative.* South Eastern Regional Lipid Conference, Cashiers, NC, November 1-3, 2000

- Funding applied for based on work supported by this award

1. Susan G. Komen Breast Cancer Foundation Dissertation Award. *PPAR γ Induced Apoptosis Requires de novo Gene Expression in Breast Cancer Cells: searching for key molecular targets.* (submitted March 15, 2001)
2. Wake Forest University Comprehensive Cancer Center. *PPAR γ and soy phytoestrogens as possible therapy for breast cancer.* \$10,000 (submitted March 15, 2001)

Conclusions

Naturally occurring derivatives of arachidonic acid metabolism are potent and effective activators of PPAR γ . The most potent of these derivatives is 15deoxy $\Delta^{12,14}$ PGJ₂ (15dPGJ₂), the dehydration and isomerization product of prostaglandin D₂ (PGD₂). 15dPGJ₂ induces PPAR γ mediated transcriptional activation leading to the synthesis of critical gene products involved in cell cycle arrest and apoptosis. Of these gene products, expression of the cyclin dependent kinase inhibitors, p21 and p27, is associated with marked cell cycle arrest with subsequent apoptosis involving caspase-3. Although 15dPGJ₂ inhibits NF κ B mediated transcription, this likely represents a minor contribution to 15dPGJ₂ induced apoptosis in breast cancer cells. Investigations into altered fatty acid metabolism pathways are underway and may yield clues as to how arachidonic acid derivative exert such potent anti-neoplastic activity in breast cancer cells. 15dPGJ₂ may represent a novel class of therapeutic molecules for the PPAR γ mediated treatment of breast cancer.

References

1. Clay CE, Namen AM, Fonteh AN, Atsumi G, High KP, Chilton FH, 2000, 15deoxy Δ 12,14PGJ₂ induces diverse biological responses via PPAR γ activation in cancer cells. *Prostaglandins and Other Lipid Mediators* 62:23-32
2. Clay CE, Namen AM, Atsumi G, Trimboli AJ, Fonteh AN, High KP, Chilton FH, 2001, The magnitude of PPAR γ activation is associated with important and seemingly opposite biological responses in breast cancer cells. *Journal of Investigational Medicine* (in press)

Appendices

Appendix 1: **Mechanisms of 15deoxy $\Delta^{12,14}$ PGJ₂ induces apoptosis in breast cancer cells.** 15dPGJ₂ induced apoptosis in breast cancer cells involves the expression of critical gene products, such as p21 and p27, via the activation of PPAR γ . NF κ B signaling represents a minor contribution, if any, to 15dPGJ₂ induced apoptosis in breast cancer cells. Activation of phospholipases (PLA₂) and inhibitors of AA metabolism, such as NSAIDs, triacsin C and CoA-IT inhibitors, increase free AA levels. 15dPGJ₂ induced reactive oxygen species (ROS) that oxidize arachidonic acid may generate oxidized lipid products that may further activate PPAR γ .

